Nutrient-Element Balance

by C. B. SHEAR and H. L. CRANE

BALANCE is a fundamental part of nature's law. But man's activities have a way of upsetting nature's balance and usually it takes a serious unbalance to make us see the situation and try to correct it.

Our increased concern over our own diets exemplifies an unbalance. The variety of foods that comprise the average normal diet should provide enough of the essential minerals and vitamins to meet our normal requirements. But not so. Many of the soils on which food crops are grown do not supply the plants with sufficient minerals to meet our needs or to enable the plants to synthesize vitamins in quantities to meet our demands. Further, and worse, we are not satisfied to use many plant products, particularly the cereals, in the form in which nature gives them to us, but demand that they be processed and "purified." These purifying processes remove some of the nutrients, and unless we know which and how much of the nutrients are removed, and supply them in our diets from other sources, we do not get enough of them.

Much the same situation exists with respect to the nutrition of our crops. The soils upon which plants depend for their food materials developed from minerals, which originally contained a fairly well-balanced supply of the essential mineral nutrients for the plants that became native to each soil. Plants with different nutrient requirements developed on soils having different powers to supply nutrients. Many soils, in their virgin state, do not furnish a balanced nutrient supply for agricultural crops. Man, however, has not restricted his cultivation to the soils best suited to the crops he wants to grow, nor has he been careful to protect the soil from erosion and leaching. Furthermore, he has continued to crop the soil year after year and has failed to return to the soil all of the nutrients removed in the crops produced. The organic matter of the soil, one function of which is to act as a reservoir of slowly available nutrients, has also been allowed to be depleted.

When America was a predominantly agricultural country, a high proportion of the products of the land was returned to the soil in the form of manure, thus helping to maintain the original soil fertility. As the country became more industrialized and the farm mechanized, less and less of the material produced on the land was returned to the soil. The farmer came to depend more and more on chemical fertilizers to maintain crop production.

The so-called complete chemical fertilizers that he used generally contained only three "plant food" elements, nitrogen, phosphorus, and potassium. Even they were not supplied in the quantities or proportions in which they were removed in the crops. In the early days of commercial fertilizers, the materials used in making them were of low grade, and contained substantial quantities of other elements of value in crop production. When fertilizers of high analysis were developed, it became necessary to use purified materials in compounding them, with the result that they contain few or no impurities. Calcium, in the form of lime, was applied in some localities as a means of correcting soil acidity, but it was not generally considered a plant nutrient, but rather a soil amendment.

The other chemical elements that the plant physiologist has determined in the laboratory to be essential for normal plant growth were thought to be required in such small quantities that they would never be of practical concern to the farmer. It has been only within the last two decades that deficiencies of such elements as magnesium, manganese, zinc, boron, and copper have been observed and diagnosed on plants growing on our principal agricultural soils, even by experienced horticulturists and agronomists. Only more recently have we recognized that the prevailing practice of returning to the soil only nitrogen, phosphorus, potassium, sulfur, and sometimes calcium was hastening the depletion of the other plant nutrients through increased crop production.

The explanation of this depleting effect of the so-called "complete fertilization" now seems quite simple. Continued application of only part of the necessary plant food materials maintained crop yields at the level that the available supply of the other nutrients in the soil would permit. As each succeeding crop was removed from the land, the supply of these other essential nutrients became less and less. The effect of their diminishing supply was reflected in reduced plant growth and yields long before their effect was evident in definite symptoms of malnutrition. It was not until these advanced symptoms appeared and their causes determined that the failure of the "complete fertilizer" to maintain the original producing power of the soil was recognized. Man, by his lack of knowledge regarding nature's complex balance, had now brought

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about a condition that made it necessary for him to determine the balance required for his crops and find means of obtaining and maintaining that balance. This was no simple task.

The first method of attacking the problem was to try to determine the quantities of the many essential elements in the soil. The method produced valuable information about the chemical composition of the soil, but it soon became evident that the amounts of the elements extracted from the soil by the various solvents employed in the laboratory did not necessarily represent the amounts of those elements available to a plant growing in that soil. Evidently the plant had its own way of obtaining its nutrients from the soil.

Perhaps the answer lay in "asking" the plant what it needed and what it was able to get from the soil. The only means of "asking" the plant was through chemical analysis of the plant, or some part of it.

The idea of making chemical analyses of plants or plant parts was not new. Thousands of analyses for certain elements in many plants had been made. Much needed to be learned, however, regarding the relationships between plant composition and plant growth and also the factors that influence the absorption of nutrients from the soil and their accumulation in the plant. Only with such information could the results of plant analyses be interpreted in terms of nutritional requirements. Our information in this field is still meager. Nevertheless, for certain crops enough of the principles have been determined to permit surprisingly accurate diagnoses of the causes of nutritional disturbances to be made by means of leaf analyses.

Let us see what some of these principles are and how they can be applied to the diagnoses and correction of nutritional disorders.

First of all, we must select carefully the part of the plant to be sampled for analysis. The leaves are the factories in which are manufactured the food that is used by the plant to build tissue and as the source of energy to carry on its life processes. It is here, in the presence of chlorophyll (the green coloring matter), that the energy of sunlight is utilized to combine the raw materials obtained from the soil and the air into food (carbohydrates, proteins, and fats). The exact part that each essential mineral element plays in the complex chemical processes involved in the manufacture of these foods and in their utilization by the plant in growth are not all understood. It is known, however, that unless carbon, hydrogen, and oxygen, which are obtained from air and water, and nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, zinc, copper, and boron, and perhaps other elements, which are obtained from the soil, are all available to the plant, it cannot grow. If maximum growth and yield are to be obtained, all these elements must be present in the leaves in the proper quantities and proportions.

Because of these facts, and because sufficient leaf tissue for chemical analysis can be removed from the plant without causing permanent damage, leaves are the ideal part of the plant to use for analysis.

The stage in the development of the plant at which the leave are sampled and the position of the leaves are important. The quantity and proportion of the different mineral elements in the leaves vary greatly during the course of the growing season. They also vary according to the position of the leaf on the shoot and, in trees, the position of the shoot on the tree. It is therefore necessary to take the leaves to be analyzed from comparable locations on the plant and shoot, preferably from the median portion. Furthermore, they should be taken when the plants are in the same physiological condition, as for example, soon after all terminal growth of the shoot has ceased or at the time of fruit maturity. Without such a carefully standardized sampling procedure the results of leaf analysis would be of little value in diagnosing the nutritional condition of the plant.

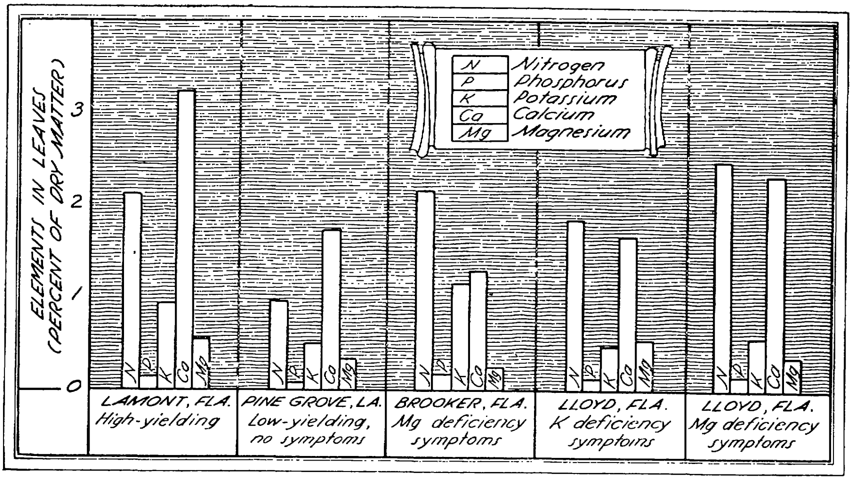
Many carefully controlled experiments in which analyses were made of leaves from thousands of plants grown under hundreds of different conditions of nutrient supply were necessary to gain the knowledge required to diagnose the nutritional condition of field-grown plants on the basis of their leaf composition.

The idea has prevailed a long time that for each crop there was a definite minimum leaf content for each essential element: If the content of a given element in the leaves fell below the minimum for that element, a deficiency, evidenced by leaf symptoms, would result. A plant was not usually recognized as being deficient in a given element until symptoms characteristic of a deficiency of that element appeared on the plant.

The results of recent work in plant nutrition show that these beliefs do not agree with the facts. Some of these results have even made it necessary for us to revise our conception of what constitutes a deficiency.

The first and only infallible symptom of the deficiency of any element is evidenced by a reduced rate of growth and, unless a more severe nutritional unbalance develops later, that will be the only symptom expressed. Because of the innumerable possible nutritional conditions that might be responsible for reduced growth, it would be impossible to determine its cause by merely examining the plant externally. On the other hand, to wait until the nutritional unbalance had become so severe as to produce symptoms would result in serious economic loss through reduced yields. Because of the great similarity between the symptoms of deficiencies of different elements, and because it is now recognized that symptoms once thought to be typical of the deficiency of a certain element may result from a number of different conditions of unbalanced nutrition, the most dependable means of diagnosis, even in advanced stages, is by leaf analysis.

We now know that when the available supply and the consequent



This chart, based on experiments with tung trees in five different areas, shows the resulting balance of leaf elements under various conditions of soil fertility.

accumulation of one nutrient element is reduced, the plant responds by accumulating an increased quantity of some other element or elements. Conversely, when an increased accumulation of one element is brought about by an increase in its available supply, the plant responds by accumulating a smaller quantity of some other element or elements. Thus it becomes obvious that we cannot consider the effects of the altered supply of one element in terms of that element alone, but must consider its effects in terms of the altered accumulation of all of the elements that are affected. The situation is further complicated by the fact that the magnitude of the effects an altered accumulation of one element will have on the accumulation of others is influenced not only by the chemical nature of the altered element but also by the available concentration of all the other elements. This phenomenon has been variously termed antagonism, compensating effect, or competition.

Perhaps the outstanding competitive effects of the nutrient elements are illustrated by the interactions among the three principal bases occurring in plants—potassium, calcium, and magnesium.

Potassium is the most active, chemically, of the three and, therefore, exerts a more pronounced effect on the accumulation of calcium and magnesium than do either of the latter on potassium or on one another. Magnesium is second and calcium third in this respect. When the potassium content of the leaf of a plant is increased through increasing the available potassium supply without at the same time increasing the available supply of calcium and magnesium, the accumulation of these latter two will be decreased, the decrease of calcium being of a greater magnitude than that of magnesium. If magnesium accumulation is increased, both potassium and calcium will decrease, calcium generally being more affected than potassium, while an increase in calcium usually results in a greater decrease in magnesium than in potassium.

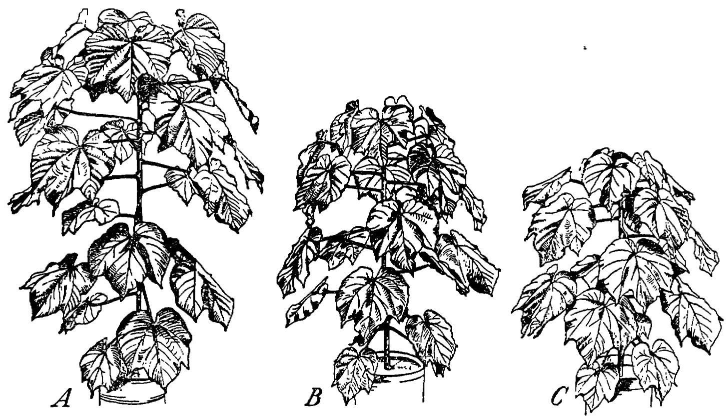
Only within the past few years have we recognized that symptoms of the deficiency of one element can be brought about by an excessive accumulation of one or more of the other elements. Several workers have recently demonstrated on a number of crops the occurrence of magnesium deficiency caused by the excessive accumulation of potassium. They have been able experimentally to induce symptoms of magnesium deficiency by applying excessive amounts of calcium or induce signs of calcium or potassium deficiency by causing the excessive accumulation of either or both of the other two bases.

We have had to change our idea of what constitutes a deficiency because of new data obtained from analyses of leaves from plants exhibiting deficiency symptoms caused by excessive accumulations of other elements. The results of leaf analyses have demonstrated that it is not necessary for the percentage—or absolute amount—of an element in the leaf to drop below a definite level in order for a deficiency to exist. The controlling factor in the occurrence of a deficiency is the relationship or balance between the level of the critical element and the levels of all of the other elements in the leaf.

That a low level of an element in the leaves of a plant results in characteristic symptoms of a deficiency only when some other element or elements are unproportionately high can be well illustrated by comparing the analyses of leaves from tung trees grown under different conditions of soil fertility. The accompanying chart shows the percentage of five elements in the leaves of tung trees under various conditions of fertility.

The orchard at Lamont, Fla., is one of the highest yielding tung orchards in the United States. Although the concentrations of the mineral nutrients in the leaves from trees in this orchard may not indicate the best possible balance, they do represent a high level of nutritional intensity and balance. The leaf analyses from the trees at Pine Grove, La., represent extreme contrasts with those from Lamont. The level of each element is only about one-half of that found for the same element in the leaves from the Lamont orchard, yet the elements occur in very nearly the same proportions in the leaves from both orchards. Because of the low level of all of the elements in the leaves from Pine Grove, these trees made little growth and yielded poorly. However, because a proper balance between the elements was maintained in the leaves, no symptons of malnutrition other than reduced growth and yield appeared.

If we look at the results of some of the other leaf analyses shown in the chart, we can see the effects of increasing the leaf content of only part of the mineral nutrients. The data from the orchard at Brooker,



	A					B					C				
NUTRIENT ELEMENT	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
CONCENTRATION SUPPLIED—P.P.M.	162	27	81	232	48	162	9	27	232	48	162	9	27	232	12
CONCENTRATION IN LEAVES—PCT.	2.87	.22	1.49	2.48	.34	2.84	.17	.55	2.37	.43	2.71	.13	1.77	3.25	.18
HEIGHT—CENTIMETERS	107					79					67				
TOTAL PLANT WEIGHT—GRAMS	1,042					831					748				

Here are three 8-month-old seedling tung trees grown in sand cultures. All received solutions containing the same concentrations of the essential elements other than those listed under each seedling. Seedling *A* made good growth indicating a good balance of nutrients; seedling *B* received insufficient potassium in proportion to the other nutrients. Note from data under seedling *B* the increased accumulation of magnesium in the leaves along with the decreased potassium accumulation. Less growth is the only evidence of nutritional unbalance; seedling *C* did not get enough magnesium. The increased accumulation of both potassium and calcium, accompanied by decreased magnesium accumulation, adversely affected growth.

Fla., show what could be expected were trees in the condition of those at Pine Grove given a "complete fertilizer" consisting of only nitrogen, phosphorus, and potassium. The levels of these three elements in the leaves from the trees at Brooker are even higher than those found in the good orchard at Lamont. The levels of calcium and magnesium, however, are even lower than those in the leaves from Pine Grove. This extreme unbalance resulted in severe symptoms of magnesium deficiency and greatly reduced growth and yield.

The data for the leaf analysis from one of the orchards at Lloyd, Fla., indicate what might be expected should an orchard in the condition of that at Pine Grove be fertilized with only nitrogen, phosphorus, and magnesium. Here, the leaf content of these three elements is very nearly that of the leaves from the Lamont orchard, while the contents of potassium and calcium are almost identical to those from Pine Grove. This unbalance resulted in the appearance of potassium-deficiency symptoms, poor growth, and low yield. The analysis of leaves from the other orchard at Lloyd illustrates still another unbalanced condition due to improper fertilization. In this case, nitrogen, phosphorus, and calcium have been maintained at high levels, while potassium and particularly magnesium have remained low. The result has been the occurrence of magnesium-deficiency symptoms.

The accompanying drawing shows some of the relationship between leaf composition and growth, certain of the competitive effects among the three major bases, and decreased growth as the only sign of nutrient unbalance. Compare the leaf analysis data given at the bottom of the illustration and those given in the chart and you will see the similarity in the concentrations of the mineral elements found in leaves from trees grown in properly conducted sand-culture experiments and those found in the leaves of field-grown trees. This similarity makes possible the interpretation of leaf analyses from field-grown trees on the basis of data obtained from sand-culture experiments.

Samuel Merrill, Jr., formerly of the United States Laboratory for Tung Investigations, Bogalusa, La., and S. R. Greer, of the Mississippi Agricultural Experiment Station, Poplarville, Miss., have obtained leaf analyses and growth measurements on tung trees that show that, when the concentration of all the essential elements with the exception of nitrogen and phosphorus are high, it is necessary to increase the accumulation of both elements in order to increase growth. The application of either of these elements alone did not result in increased growth, even though the leaf content of the applied element increased.

The necessity for maintaining a proper balance among the elements in the leaf is not restricted to the five elements so far discussed. The so-called minor elements—iron, manganese, zinc, copper, and boron—must be accumulated in the proper proportions to one another and to the other elements if satisfactory crop production is to be maintained. Also, just as is the case with the other nutrient elements, the accumulation of the minor element in the leaves is not dependent alone on their available concentration, but is influenced by the available concentrations of all of the other elements.

Experiments with the tung tree have shown that the appearance of symptoms associated with manganese deficiency may result from a high accumulation of any one of the three major bases, and that these symptoms are the most severe when all three of the bases are high in proportion to manganese. It has also been demonstrated that the three major bases exert the same influence on iron, zinc, copper, and boron. Thus, conditions promoting increased accumulations of calcium, magnesium, and potassium work in two ways to bring about deficiencies of one or more of the minor elements: First, by depressing their accumulation, and second, by increasing the concentrations required in the leaf to create a proper balance with the other elements.

Because the accumulation of each of the minor elements is affected to a different degree by the accumulation of each of the major bases, an unbalanced accumulation of potassium, calcium, and magnesium may also result in an unbalanced relationship between two or more of the minor elements. In experiments with tung trees, for example, too low a level of potassium in proportion to calcium and magnesium has resulted in an unfavorably high ratio of manganese to copper in the leaves. Other examples of similar phenomena have been observed on a number of different crop plants. For instance, boron toxicity may occur when the level of one or more of the three major bases is unduly low, yet at high levels of the bases the plant may become boron deficient. This deficiency is not the result of depressing the boron content of the leaves below a critical level, but is caused by an unfavorable balance between boron and one or more of the bases.

It has been long known, and demonstrated on numerous crop plants, that an excess of iron in proportion to manganese may induce manganese deficiency and that an excess of manganese in proportion to iron may induce iron deficiency.

S. G. Gilbert and M. Drosdoff, of the United States Laboratory for Tung Investigations, Gainesville, Fla., and H. M. Sell, of the Michigan Agricultural Experiment Station, have demonstrated that increasing the nitrogen content of tung leaves already low in copper will result in severe copper-deficiency symptoms. This was found to be true even though the copper content of the leaves in the fall when the copper-deficiency symptoms were most severe was higher than that of the leaves early in the growing season when the copper deficiency was much less pronounced.

Only a few of the more important relationships between the essential elements have been discussed here. Many other relationships and other instances of decreased growth or other symptoms of malnutrition resulting from improper nutritional balance within the plant have been demonstrated on a number of crop plants. The relationships between the elements and the examples of unbalance which have been given should indicate to the reader that the problem of plant nutrition is by no means a simple one. It should also be evident that the use of deficiency symptoms to diagnose nutritional difficulties is like waiting until the horse is stolen before locking the stable. In order to reap the maximum returns from the land our crop plants must be maintained in a well-balanced nutritional condition. This cannot be accomplished through hit-or-miss fertilization but must result from the integration and application of all of our available knowledge concerning the nutrient requirements of each crop, the nutrient-supplying power of our soils, and the effects of the rate of supply of each element on the accumulation and function of all the other elements in the plant.

It is unfortunate that our present knowledge in these respects is too inadequate for most crops to permit the determination of their fertilizer requirements by means of leaf analysis. It is hoped that such knowledge will be accumulated in the near future. When such knowledge is available, it should be possible for properly trained soil scientists and plant physiologists to make accurate fertilizer recommendations on the basis of complete leaf analyses.

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FOR FURTHER READING

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ALSO, IN THIS BOOK

Phosphate Fertilizers, by W. H. Pierre, page 554.
Use of Nitrogen Fertilizers, by F. W. Parker, page 561.
The Use of Minor Elements, by Matthew Drosdoff, page 577.